Spallation Neutron Source Project, Los Alamos National Laboratory

Pressure Drop Calculation For The X, Y Slits in the Diagnostic Plate (D Plate) Beam Line.

Purpose:

The purpose of this calculation is to determine the coolant water pressure drop in the X, and Y and to confirm that the water-cooling system that is proposed to cool the D Plate is adequate.

Assumptions:

- The maximum pressure drop across the slits cannot exceed 30 psi. John Bernardin, who is the project leader for the linac cooling system, determined this as the maximum allowable pressure drop.
- Also, there are seven bends in the cooling circuit. Four of these bends are rectangular cross sections and the bends are approximately 90 degrees. Intuitively, these bends will have less turbulence then round cross sections, but to be conservative, round cross sections were analyzed. In addition, the other three bends were analyzed as sharp 90 degree bends and an equivalent length diameter for each bend was assumed to be 64 diameters.
- The average power intercepted by the slits is 97.5 watts per Steve Ellis.
- The pressure drop across the globe valve and flow meter is assumed to be about 6 psi. From previous calculations, this seems like a safe assumption.

Results:

With a flow rate of 0.25 gallons per minute, the final pressure drop across the slits from supply manifold to return manifold is about 20 psi. The temperature rise in the water is about 2 degrees Kelvin.

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The purpose of this calculation is to determine if the XY slits used in the D Plate beam line can be water cooled with the proposed water system that can deliver 30 psi of water pressure across the slits. This calculation calculates the coolant pressure drop across the X Y slits and the temperature rise in the water. It does not calculate the temperature of the copper slit plates nor does it include a detail calculation for the pressure drop across the valve, flowmeter, and turns, etc., in the lines to and from the slits. From previous calculations, this pressure drop will be assigned 6 psi. This calculation does not warrant that kind of detail.

Inputs:

$flow\_rate := 0.25 \frac{gal}{min}$

$average\_power := 97.5W$ Average power to the slit

$feed\_tube\_diam := \frac{3}{16} in$

$feed\_tube\_wall := 0.035in$

$feed\_tube\_length := 30in$

$return\_tube\_diam := \frac{5}{16} in$

$return\_tube\_wall := 0.016in$

$return\_tube\_length := 26in$

$cooling\_slot\_length_{XY\_plate} := 17in$

$\rho := 62.4 \frac{lb}{ft^3}$ Density of water

$cooling\_slot\_width := 0.125in$

$\rho = 999.552 \frac{kg}{m^3}$

$cooling\_slot\_depth := 0.1875in$

$flex\_tube_{ID\_feed} := 0.1875in$

$\mu := 959 \cdot 10^{-6} \frac{N \cdot sec}{m^2}$ Viscosity of the water

$flex\_tube_{ID\_return} := 0.3125in$

$\Delta P_{valve\_flow\_etc} := 6 \frac{lb}{in^2}$ Catch all pressure drop for the valve, flow meter, etc.

The cooling water flows down the inside of the feed tube and returns through the inside of the return tube which also encases the feed tube (concentric tubes). The hydraulic diameter of the inside tube is just it's diameter, but we need to find the hydraulic diameter of the outside tube.

$$inside\_diam_{return\_tube} := return\_tube\_diam - 2 \cdot return\_tube\_wall$$

$$inside\_diam_{return\_tube} = 7.125 \times 10^{-3}\,m$$

$$flow\_area_{return\_tube} := \frac{\pi}{4}\left(inside\_diam_{return\_tube}^{\;2} - feed\_tube\_diam^2\right)$$

$$flow\_area_{return\_tube} = 2.205 \times 10^{-5}\,m^2$$

$$wetted\_perimeter := \pi \cdot \left(feed\_tube\_diam + inside\_diam_{return\_tube}\right)$$

$$wetted\_perimeter = 0.037\,m$$

$$hydraulic\_diam_{return\_tube} := 4 \cdot \frac{flow\_area_{return\_tube}}{wetted\_perimeter}$$

$$hydraulic\_diam_{return\_tube} = 2.362 \times 10^{-3}\,m$$

Calculate the pressure drop in the feed tube.

$$diam\_feed := feed\_tube\_diam - 2 \cdot feed\_tube\_wall$$

$$diam\_feed = 2.984 \times 10^{-3}\,m$$

$$V_{feed\_water} := \frac{flow\_rate}{\left(\frac{\pi \cdot diam\_feed^2}{4}\right)}$$

$$V_{feed\_water} = 2.255\,\frac{m}{s}$$

$$Re_D := \frac{\rho \cdot V_{feed\_water} \cdot diam\_feed}{\mu}$$ **Reynolds number**

$$Re_D = 7.013 \times 10^3$$

$$friction_f := 0.184 \cdot Re_D^{-\left(\frac{1}{5}\right)}$$ Page 372, Eq 8.21,for a smooth surface, Incropera and Dewitt

$$friction_f = 0.031$$ Friction factor for smooth surfaces

$$mass_{flow} := flow\_rate \cdot \rho$$ Mass flow rate. Need this to calculate the temperature rise in the water.

$$mass_{flow} = 0.016 \frac{kg}{s}$$

The pressure drop across the feed tube is:

$$g = 9.807 \frac{m}{s^2}$$ $$V_{feed\_water} = 2.255 \frac{m}{s}$$

$$head\_loss := friction_f \cdot \frac{(feed\_tube\_length) \cdot V_{feed\_water}^2}{diam\_feed \cdot 2 \cdot g}$$ Eq 8.11, page 196

$$head\_loss = 2.072 \, m$$

$$delta\_pressure_{feed\_tube} := \rho \cdot head\_loss$$

$$delta\_pressure_{feed\_tube} = 2.945 \frac{lb}{in^2}$$ **This is the pressure drop across the feed tube going into the slit.**

The slit is made of a copper plate and the cooling slot, which is cut in the plate, is 0.125 wide and 0.1875 deep, and rectangular in shape

$$hydraulic\_diam_{plate\_slot} := 4 \cdot \frac{(cooling\_slot\_width \cdot cooling\_slot\_depth)}{2 \cdot (cooling\_slot\_width + cooling\_slot\_depth)}$$

$$hydraulic\_diam_{plate\_slot} = 3.81 \times 10^{-3} \, m$$

Find the equivalent length added by the four bends in the hydraulic circuit

$R_1 := 0.25 \cdot in$ This is the bend radius.

$\frac{R_1}{hydraulic\_diam_{plate\_slot}} = 1.667$ $Eq\_length := 9.5 \cdot hydraulic\_diam_{plate\_slot}$

$Eq\_length = 0.036\,m$

$bend\_len := 4 \cdot Eq\_length$

$bend\_len = 0.145\,m$

Equivalent length calculation was done using the Crane Company's Technical Paper #410, "Flow of Fluids Through Valves, Fittings and Pipe, page A-27

Calculate the pressure drop across the copper plate.

$$V_{plate} := \frac{flow\_rate}{\left(\frac{\pi \cdot hydraulic\_diam_{plate\_slot}{}^2}{4}\right)}$$ $V_{plate} = 1.383\,\frac{m}{s}$

$$Re_{D\_plate} := \frac{\rho \cdot V_{plate} \cdot diam\_feed}{\mu}$$

Reynolds number

$Re_{D\_plate} = 4.303 \times 10^3$

$$friction_{f\_plate} := 0.184 \cdot Re_D^{-\left(\frac{1}{5}\right)}$$ Friction factor

$$head\_loss_{plate} := friction_{f\_plate} \cdot \frac{\left(cooling\_slot\_length_{XY\_plate} + bend\_len\right) \cdot V_{plate}{}^2}{hydraulic\_diam_{plate\_slot} \cdot 2 \cdot g}$$

$head\_loss_{plate} = 0.462\,m$

$delta\_pressure_{plate} := \rho \cdot head\_loss_{plate}$

$\boxed{delta\_pressure_{plate} = 0.657\,\frac{lb}{in^2}}$

This is the pressure drop across the copper plate

The pressure drop across the return tube is:

$$V_{return\_tube} := \frac{flow\_rate}{\left(\frac{\pi \cdot hydraulic\_diam_{return\_tube}^{2}}{4}\right)} \qquad V_{return\_tube} = 3.599 \frac{m}{s}$$

$$Re_{D\_return} := \frac{\rho \cdot V_{return\_tube} \cdot diam\_feed}{\mu}$$ **eynolds number**

$$Re_{D\_return} = 1.12 \times 10^{4}$$

$$friction_{f\_return} := 0.184 \cdot Re_{D}^{-\left(\frac{1}{5}\right)}$$ Friction factor

$$head\_loss_{return} := friction_{f\_return} \cdot \frac{(return\_tube\_length) \cdot V_{return\_tube}^{2}}{hydraulic\_diam_{return\_tube} \cdot 2 \cdot g}$$

$$head\_loss_{return} = 5.78\,m$$

$$delta\_pressure_{return\_tube} := \rho \cdot head\_loss_{return}$$

$$delta\_pressure_{return\_tube} = 8.217 \frac{lb}{in^{2}}$$

This is the pressure drop across the straight concentric return tube

There are three right angle bends in the water cooling circuit. Find the equivalent lengths and there pressure drops. Note, the geometries are different in each 90 degree bend, but I am simplifying the calculation and assuming all of the bends diameters are the same.

$R_1 := 0 \cdot in$ This is the bend radius.

$$\frac{R_1}{hydraulic\_diam_{plate\_slot}} = 0 \qquad Eq\_length_{90} := 64 \cdot hydraulic\_diam_{plate\_slot}$$

$$Eq\_length_{90} = 0.244\,m \qquad V_{return\_tube} = 3.599 \frac{m}{s}$$

$$bend\_len_{90} := 3 \cdot Eq\_length \qquad friction_{f} = 0.031$$

$$bend\_len_{90} = 0.109\,m$$

$$head\_loss_{90} := friction_{f} \cdot \frac{bend\_len_{90} \cdot V_{return\_tube}^{2}}{hydraulic\_diam_{return\_tube} \cdot 2 \cdot g}$$

$$head\_loss_{90} = 0.95\,m$$

$$delta\_pressure_{90bends} := \rho \cdot head\_loss_{90}$$

$$\boxed{delta\_pressure_{90bends} = 1.351\,\frac{lb}{in^2}}$$

This is the pressure drop across the three 90 degree bends.

The total pressure drop across the X Y slit is:

$$delta\_P\_XYslit := delta\_pressure_{feed\_tube} + delta\_pressure_{plate} \cdots + delta\_pressure_{return\_tube} + delta\_pressure_{90bends}$$

$$\boxed{delta\_P\_XYslit = 13.171\,\frac{lb}{in^2}}$$

This is the total pressure drop across the mechanized slit

Calculate the pressure drop from the manifold to the X or Y slit. The slits are not all set at a uniform distance from the manifold. So I will take the worst case and calculate the pressure drop. The longest distance from the water manifold to the X or Y slit is 80 inches and we will use a 3/16 ID flexible tube..

$$flex\_tube_{ID\_feed} = 0.187\,in$$

$$V_{flex\_hose\_feed} := \frac{flow\_rate \cdot 2}{\left[\frac{\pi \cdot \left(flex\_tube_{ID\_feed}{}^2\right)}{4}\right]}$$

$$V_{flex\_hose\_feed} = 1.771\,\frac{m}{s}$$

$$Re_{D\_hose\_feed} := \frac{\rho \cdot V_{flex\_hose\_feed} \cdot diam\_feed}{\mu}$$ **eynolds number**

$$Re_{D\_hose\_feed} = 5.508 \times 10^3$$

$$friction_{f\_hose\_feed} := 0.184 \cdot Re_D^{-\left(\frac{1}{5}\right)}$$ Friction factor

$$head\_loss_{hose\_feed} := friction_{f\_hose\_feed} \cdot \frac{(bend\_len) \cdot V_{flex\_hose\_feed}^{2}}{hydraulic\_diam_{return\_tube} \cdot 2 \cdot g}$$

$$head\_loss_{hose\_feed} = 0.307\,m$$

$$delta\_pressure_{flex\_hose\_feed} := \rho \cdot head\_loss_{hose\_feed}$$

$$delta\_pressure_{flex\_hose\_feed} = 0.436\,\frac{lb}{in^{2}}$$

This is the pressure drop in the hose line from the manifold to the slit.

Calculate the pressure drop from the X or Y slit to the manifold. The slit do not all set at a uniform distance from the manifold. So I will take the worst case and calculate the pressure drop. The longest distance from the water manifold to the X or Y slit is 80 inches and we will use a 5/16 ID flexible tube..

$$flex\_tube_{ID\_return} = 0.313\,in$$

$$V_{flex\_hose\_return} := \frac{flow\_rate \cdot 2}{\left[\frac{\pi \cdot \left(flex\_tube_{ID\_return}^{2}\right)}{4}\right]}$$

$$Re_{D\_hose\_return} := \frac{\rho \cdot V_{flex\_hose\_return} \cdot diam\_feed}{\mu}$$ **Reynolds number**

$$Re_{D\_hose\_return} = 1.983 \times 10^{3}$$

$$friction_{f\_hose\_return} := 0.184 \cdot Re_{D}^{-\left(\frac{1}{5}\right)}$$ Friction factor

$$V_{flex\_hose\_return} = 0.637\,\frac{m}{s}$$

$$head\_loss_{hose\_return} := friction_{f\_hose\_return} \cdot \frac{(bend\_len) \cdot V_{flex\_hose\_return}^{2}}{hydraulic\_diam_{return\_tube} \cdot 2 \cdot g}$$

$$head\_loss_{hose\_return} = 0.04\,m$$

$$\text{delta\_pressure}_{\text{flex\_hose\_return}} := \rho \cdot \text{head\_loss}_{\text{hose\_return}}$$

$$\boxed{\text{delta\_pressure}_{\text{flex\_hose\_return}} = 0.057 \frac{\text{lb}}{\text{in}^2}}$$

This is the pressure drop from the slit back to the water manifold.

Total pressure drop from manifold through the X or Y slit, back to the manifold.

$$\text{total\_pressure\_drop} := \text{delta\_pressure}_{\text{flex\_hose\_feed}} + \text{delta\_pressure}_{\text{flex\_hose\_return}} \cdots + \text{delta\_P\_XYslit} + \Delta P_{\text{valve\_flow\_etc}}$$

$$\boxed{\text{total\_pressure\_drop} = 19.664 \frac{\text{lb}}{\text{in}^2}}$$

This is the total pressure drop calculated from the supply water manifold to the return manifold.

Calculate the temperature rise of the cooling water.

$$\text{mass}_{\text{flow}} := \text{flow\_rate} \cdot \rho$$

$$\text{mass}_{\text{flow}} = 0.016 \frac{\text{kg}}{\text{s}}$$

$$c_p := 4.178 \cdot \frac{\text{J} \cdot 1000}{\text{kg} \cdot \text{K}}$$

Specific heat of water

$$c_p = 4.178 \times 10^3 \frac{\text{J}}{\text{kg} \cdot \text{K}}$$

$$\text{water\_temp}_{\text{gain}} := \frac{\text{average\_power}}{\text{mass}_{\text{flow}} \cdot c_p}$$

Page 381, Eq 8.41,Incropera and Dewitt

$$\boxed{\text{water\_temp}_{\text{gain}} = 1.48\,\text{K}}$$

This is the temperature rise in the cooling water after it flows through the slit.